PIER Energy-Related Environmental Research
Environmental Impacts of Energy Generation, Distribution and Use

Measurement of Large-Scale Gene Flow: A Pathway to Understanding Adaptation and the Genetics of Climatic Tolerance

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Contractor: University of Notre Dame
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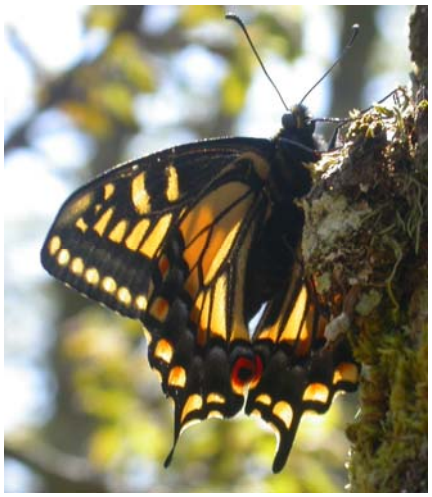
The Issue

Greenhouse gas emissions—from fossil-fueled power plants, among other sources—are altering climatic conditions in California. The state's mean temperature is expected to warm 3°–5°C (5.4°–9°F) by 2100, with associated changes in precipitation and possible increases in the frequency of extreme weather events.[1] The resulting effects on California's biological resources may range from minor to devastating, depending how well various species tolerate the changing conditions. To properly manage California's unique biological resources in the face of climatic change, scientists need to understand the underlying drivers of ecological responses to climate change.



Comparing the genetic diversity of Anise Swallowtail (*Papilio zelicaon*) populations to populations of another species yields fundamental insight into the gene flow dynamics that drive ecological response to climate change.

Project Description

This research project tested critical assumptions about the genetic differences between populations in California, differences that may determine the ecological responses of species to a changing climate. The project used two flagship butterflies that inhabit two of California's most prized ecosystems—oak savanna and native grassland—to study if species with differing characteristics differ in the extent to which their populations are adapted to local climates. Determining the extent of such local adaptation is critical to understanding the large-scale responses of organisms to climate change—specifically, the changing boundaries of species' distributions.

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[1] Hayhoe, K., et al. 2004. Emissions pathways, climate change, and impacts on California. *Proceedings of the National Academy of Sciences* 101: 12422–12427.

The movement, or flow, of genetic information across a species' geographic distribution is an essential determinant of a population's adaptation to local conditions. Most ecologists assume that climate change, as caused by the emission of greenhouse gases, will cause species to shift their geographic distributions poleward. However, local adaptation and genetic differentiation due to restricted gene flow among populations can change this picture considerably: if populations throughout a range are adapted to the climate that occurs in their local habitats, widespread population declines could result under climate change.

This project investigated local adaptation and the movement of genes among populations by measuring differences in the genetic sequence of individuals from different locales. The project examined two butterfly species, the Propertius Duskywing (*Erynnis propertius*) and the Anise Swallowtail (*Papilio zelicaon*) because these species capture a large difference in body size and resource specialization within a single taxonomic group. These characteristics are likely to be important determinants of interpopulation movement and thus the amount of genetic difference that accumulates among populations.

To assess the extent of genetic differences among populations, the study measured the sequence similarity and the number of alleles (genetic forms) found at various sites. Collections were made throughout California and combined with collections from elsewhere in the Pacific Northwest to generate a latitudinal gradient capturing the northern and southern extensions of the species' ranges. Specimens of both species were sought wherever host plants co-occurred with nectar resources. Collected specimens were assessed for genetic diversity using mitochondrial genes (mtDNA) and microsatellite markers.

PIER Program Objectives and Anticipated Benefits for California

This project, funded by PIER's Environmental Exploratory Grant Program, offers numerous benefits and meets the following PIER Program objectives:

- **Evaluating the environmental effects of energy production.** Climate change from fossil fuel combustion has been identified as a major threat to the natural systems on which the state depends. This study examines if and why species respond differently to climate change based on their ecological characteristics, thereby providing fundamental insight into the impacts of climate change on California's bioresources. As such, the project provides a scientific basis for identifying and protecting species threatened by climate change.
- **Providing environmentally sound energy.** The findings of this study can be used to further assess the risks of fossil fuel emissions to the state's natural resources. Knowing those risks, policymakers can better plan for a more environmentally sound energy system.

Results

For both species, results reveal genetic differentiation of northern (British Columbia) and southern (San Diego County) populations from the rest of the study populations. The divergence of northern populations suggests the potential for local adaptation, a factor that could reduce, slow, or eliminate poleward range expansion under climate change. The southern populations are likely to decline under climate change as conditions become unsuitable; therefore, genetic diversity that occurs there may be at risk.

The study also revealed greater genetic differentiation in populations of the smaller, more specialized *E. propertius* than in the larger generalist, *P. zelicaon.* This finding suggests that even within a single phylogenetic group and in a common ecosystem, species can differ in their genetic architecture. In turn, these differences could lead to distinctive responses under climate change. In other words, the assumption that all species will shift northward under climate change may be inappropriate given the varied genetic structure of some taxa.

Further research is needed to determine if the populations that are genetically differentiated in this study also are functionally differentiated with respect to climate. Experiments or functional genomic studies are required for this next step.

In the meantime, conservation biologists should consider how populations in distinct locations will respond differently to climate change as greenhouse gas emissions continue to rise. Specific attention should be paid to both *P. zelicaon* and *E. propertius* populations in San Diego County, as they harbor unique genetic composition compared to other sites in the study region and are the most likely to experience deteriorating conditions as the climate warms. If these populations go extinct, the diversity that they harbor could be lost.

Final Report

The final report for this project can be downloaded from www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2007-043.

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